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Ice jam characteristics, Liard–Mackenzie rivers confluence:[1] Reply

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The author appreciates the discussion by Flato and Gerard regarding the sensitivity of the declining-discharge technique to the type of flow equation used and to potential errors in the field data. The technique proposed by the writers' holds considerable promise but, as discussed below, it is sensitive to a poorly defined relationship between ice floe diameter and subsurface roughness (see Beltaos 1987). It is, however, encouraging that the writers' technique results in a value of μ only "somewhat higher than that given by the author" and a range in jam thickness that "accords with the author's analysis."

The major uncertainty in the writers' technique lies with relating the subsurface roughness height to the diameter of surface ice floes (i.e., $k_i = \alpha D_{84}$). A value for α of 2–3 is suggested, based largely on relationships established for hemispherical elements and alluvial bed material. Given the myriad of complex ice forms produced by the breakup process, α probably varies over a much wider range than that suggested by the writers. The possible range in α is best illustrated by considering the extremes in ice shape produced by the breakup process. At one end of the spectrum are the flat-topped, intact floes with a low height-to-diameter ratio while at the other are the pinnacle shaped fragments with a large height-to-diameter ratio. Given the same diameter, a much lower value of α would be expected for the tabular than for the pinnacle forms. The problem of using floe diameters to define a representative k_i value for an ice jam is complicated further by the lack of data concerning the relative concentrations of the various ice forms. Although intact floes are more common in jams produced by thermal breakups and heavily fragmented pieces more germaine to dynamic mechanical breakups, both have been observed at varying concentrations throughout the length of both types of jams.

In the case of the 1983 Liard jam, the author did note that "most of the floes were less than 2 m in diameter" but would not feel confident in the writer's technique of using a simple visual estimate as the value for D_{84}. Because the estimation of μ is sensitive to the roughness height used, direct measurement of floe sizes and distribution would seem prudent, at least in the initial testing of this technique. For example, if D_{84} for the Liard jam was actually 1.0 m and assuming $\alpha = 2–3$ is applicable, then μ decreases by approximately 20% to 0.98 – 1.08 (derived from the writers' Fig. A).

Caution must also be used when assuming that the value of α derived from the surface is also applicable to the bottom of the ice accumulation, largely because of the effects of thermal erosion, especially when jams have been in place for prolonged periods. As shown by Prowse and Marsh (1987), the hydrothermal heat flow to the base of the ice jam can far exceed the atmospheric heat flow to the ice jam surface. Hence, more rounding or doming of ice fragments should occur at the base of the jam than at the surface. Because of the rapid decrease in the hydrothermal heat flow beneath ice jams (Marsh and Prowse 1987), this effect is likely to be more pronounced near the head of an ice jam and to be less important further downstream. In cases where hydrothermal heat flows are large and likely to produce a significant downstream variability in subsurface ice roughness, it might be more suitable to use a roughness parameter derived from overall flow resistance rather than from observations of surface roughness. Establishing a suitable α value is further complicated by the effects of cohesion among ice fragments (see original discussion by the author), which could lead to large and complex ice agglomerations with geometries unlike those produced by simple fracturing and fragmentation of the original ice sheet.

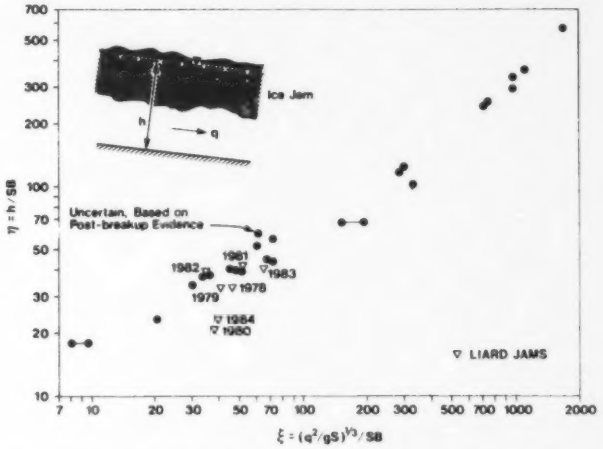

FIG. 1. Dimensionless depth (η) versus dimensionless discharge (ξ) for equilibrium jams. Other terms are river width (B), acceleration due to gravity (g), depth (h), discharge per unit width (q), and river slope (S). Data points connected by horizontal lines represent cases where ξ is known only as a range. (After Ashton, 1986.) Liard ice jams (1978–1984) are noted by inverted triangles.

In reference to the apparently large value of k_b (f_b), information about the bed material in the jam reach is meagre, although detailed studies have been conducted in upstream reaches of the Liard (e.g., B.C. Hydro 1985). Bed material in the lower 110 km of the river has been described as being "predominantly coarse gravel, cobbles, boulders and some bedrock sills." (B.C. Hydro 1985, pp. 4–9). More specific to the jam reach: "Much of the bed and the lower portion of the banks above the ferry crossing are paved with cobbles and boulders ..." and "downstream of the ferry crossing ... it is likely that the bed alluvium is deeper and finer than upstream." (Northwest Hydraulic Consultants Ltd. 1975, p. 6). Bed material size is not, however, the only reason for the relatively high value of f_b. At

[1]Discussion by G. Flato and R. Gerard. 1988. Canadian Journal of Civil Engineering, 15: this issue.

the low levels of R_h, which prevailed beneath the ice jam, the effect of other physical features that determine the channel geometry becomes increasingly important. This point has been well addressed by Beltaos (1987) in response to a similar question posed by Gerard (1987). As noted by Beltaos (1987), at very low stage "there is little physical meaning to k_b; its use is as empirical as the use of n_b and f_b but could produce a false impression of rigor." In the Liard case, the R_h value of 2.72 m is just within the "Range 1 effect" at which k_b rapidly increases relative to R_h (see [10]).

As mentioned by the author, ice conditions near the Mackenzie River Water Survey of Canada gauge at Fort Simpson remained essentially intact while further upstream, near the ice jam toe, the ice cover was characterized by large-scale fractures. A large polynya, several hundred metres in diameter, developed within the zone of fractured ice (see Prowse (1984) for detailed description of ice conditions). Frequent aerial observations of flow conditions within the polynya revealed that ice was not being released from the ice jam and therefore did not affect flow conditions at the Fort Simpson gauge. Channel geometry of the Mackenzie is based on a cross-section survey conducted by the author in the fall of 1985. The Mackenzie River slope was derived from a water surface profile conducted by Underhill Engineering Ltd. in 1980 for the British Columbia Hydro and Power Authority.

While the author does not discount the possibility of μ varying between thermally and mechanically produced jams, it is unclear why the disparity of the 1980 and 1984 points in Fig. 14 cannot be explained, at least partly, by simple overestimates in the discharge for these events.

The requested dimensionless depth (η) versus dimensionless discharge (ξ) data for the 1978–1984 Liard ice jams is shown in Fig. 1 superimposed on the data provided in Ashton (1986, Fig. 5–45). Notably, the 1980 and 1984 thermal events stand out as anomalies. Reiterating however, caution should be used in the interpretation of these results because of the uncertainty in the discharge figures.

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